TMO TECHNOLOGY DEVELOPMENT PLAN

Frequency and Timing Work Area

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OBJECTIVE:

The objective of the Frequency and Timing work area is to advance the art of technologies for frequency and time generation, distribution, and characterization in order to reduce DSN costs and enable new mission types, and to develop these technologies to such a stage that they can be transferred to Implementation.

GOALS and SIGNIFICANCE:

- Develop Linear Ion Trap Standards (LITS, LITE) with 10^{-16} performance for 1000 to 10,000 seconds. The simple design of these new standards reduces DSN cost, increases reliability, improved medium- and long-term performance will enable new radio science.
- Develop cryogenic microwave standards with 10^{-16} short-term stability together with reduced cryogenic requirements in order to meet Cassini Radio Science requirements with reduced cost, and improved operability. Additionally this technology makes possible a L.O. to enable ultimate LITS performance.
- Develop photonic technology for signal and reference transmission, frequency generation, and remote conversion capability. This technology enables antenna remoting, with reduced equipment cost to DSN and an ultra-small advanced room-temperature oscillator capability.

PRODUCTS:

- LITS Trapped Ion Frequency Standard, the original linear trap design, now being implemented in DSN
- Compact Ion Standard (LITE) shuttle trap for reduced size, improved performance
- Laser-Cooled Ion Trap, a research unit with the highest capability
- SCMO Cryogenic Osc, the 10^{-15} ultra-high short-term performance prototype
- 10K CSO Sapphire Osc provides SCMO performance with closed-cycle cooler for improved operability
- Fiber Optic Signal Transmission provides advanced capabilities for reference and antenna signals
- Photonic Signal Capability enables advanced DSN configuration concepts
- Opto-Electronic Oscillator is a new miniature ultra-stable oscillator, room temperature operation

DESCRIPTION:

Frequency and timing is an enabling technology for deep space navigation and radio science experiments. The stability of references driving transmitter exciters and receivers in a deep space station determines the precision of parameters used to navigate spacecraft in interplanetary missions. Improved frequency stability and spectral purity at the DSN also maximize the science return of deep space missions, and allow increased measurement resolution and accuracy for radio science experiments using existing hardware on spacecraft. Radio metric data experiments rely on frequency standards as an enabling technology to perform a variety of measurements including those associated with the VLBI observation of compact radio sources, planetary occultation, and spacecraft based gravitational wave detection.

The frequency and timing technology currently available at the DSN is the result of some 25 years of investment in research and development in this field. Payoffs for this investment include the improved LITS frequency standards which are now being installed in the DSN, the success of radio science experiments on missions such as Voyager which are enabled by frequency standard technology, and new radio science experiments for missions such as Cassini.

New performance capabilities are required to reduce purchase and maintenance costs and increase reliability to meet present DSN frequency and frequency transmission requirements. Hydrogen maser frequency standards with quartz crystal L.O.'s and metallic coaxial signal transmission provided the backbone of the DSN frequency reference capability for many years, with high maintenance costs associated with the masers, and weather and temperature sensitivity associated with coaxial signal transmission. These present capabilities are changing --- fiber optics has already replaced coax for reference signal transmission in DSN areas where the temperature is not controlled, and new LITS Trapped Ion frequency standards are being implemented as replacements for the masers. Both of these applications result in substantial cost savings. Fiber-optic transmission obviates the need for additional hydrogen maser frequency standards at the antenna sites for sensitive missions at a cost of $600K each.

Advances in microwave technology now make possible the use of higher (Ka-band) frequencies for spacecraft communication, which together with advances in tropospheric delay calibration and other TMO Technology, can now greatly reduce frequency degradation of spacecraft signals. New frequency standards under development as part of a DSN upgrade for the Cassini Ka-Band Experiment are an integral part of the hardware capability required to match this increased stability.

Trapped ion technology developed in the *Advanced Frequency Standard* work area has resulted in a new generation of frequency standards now being installed in the DSN. This technology is now approaching commercial technology transfer, and has reached a level of maturity and performance where very different applications can now be accurately modeled and evaluated. In addition to commercialization, flight applications to both NASA and DOD (GPS) are being actively investigated. TMOT development of a flight capability to enable end-to-end frequency and timing services and to offer new options for greater spacecraft autonomy will be proposed for FY99. The ultimate in performance for atomic frequency standards is possible only by the use of laser-cooling, and the very first JPL demonstration took place in FY97. A substantial laser-cooling effort is beginning at JPL, and a new TMOT work area has been established for laser-cooled *optical frequency standards*.

The cryogenic *Microwave Oscillator* work area development complements the trapped ion technology with a matching short-term frequency capability. The Cassini Ka-band Experiment is cofunding the development and funding the construction of the 10K sapphire oscillator, the first cryocooled frequency standard with ultra-high short-term frequency stability and ultra-low phase noise. Four units are scheduled to be installed in the DSN from FY99 to FY02. In addition to providing uninterrupted long term support for radio science experiments, these standards have the L.O. capability to enable the highest possible performance from the trapped ion standards. This capability will be first investigated in this FY. Development of a second generation of the cryogenic sapphire oscillator will be proposed for substantially reduced cost, size and maintenance. The cutting edge for this technology will be to reduce size and increase performance by operation at frequencies of 100 GHz or more using quasi-optical microwave techniques based on the whispering gallery resonator technology used in the sapphire oscillator.

Photonic development of antenna remoting capability up to X-band is being demonstrated in an installation at DSS-13, and capabilities for site-wide installation will be demonstrated this FY. Integrated signal processing will also be demonstrated, with Ka-band operation dependent on the availability of an appropriate modulator. The Optoelectronic oscillator development continues to surprise with new capabilities. With its wide applicability to low-phase noise and high-stability oscillator applications, the TMOT emphasis now focuses on noise reduction, and advanced techniques for a stabilized fiber delay line. Even now, it is not clear what OEO configuration will be first applicable to TMOT needs, but with substantial cofunding, this effort continues to rapidly advance this JPL-invented art.

DELIVERABLES:

- Continuing long-term Linear Ion Trap (LITS) Tests
- Demo and optimize Implementable LITE operation
- Demo Laser-cooled LITS with sympathetic cooling
- Demo LITS/CSO with $4x10^{-14}/\tau^{1/2}$ stability
- Optimize Long-Term LITE Parameters
- Technology Transfer, LITE Standard to Commercial Manufacturer

- Demonstrate sympathetic laser cooling in Ytterbium trap
- Sapphire compensated resonator optimization
- 2nd CSO operational, demo $3x10^{-15}$ at 10 seconds
- Technology Transfer 10K CSO
- TDA Progress Report on 10K CSO Oscillator
- Install Antenna Remoting Link at Goldstone including down-conversion
- Demo Opto-Electronic Oscillator with thermally stabilized delay
- Demo all-photonic polarization-insensitive link
- Construct dual-loop Brillouin OEO

RESOURCE REQUIREMENTS BY WORK UNIT:

	JPL Account #	FY98	FY99	FY00	FY01	FY02	FY03
Advanced Frequency Standard	412-41402	350					
Microwave Oscillator	412-41403	100					
Photonics	412-41404	170					
Optical Frequency Standard	not available	75					
Total		695	696	676	676	702	702
Total Workforce		3.45					

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Advanced Frequency Standard	
WORK UNIT IN WHICH FUNDED: Advanced Frequency Standard 412-41402	
WORK AREA: Frequency and Timing	

BRIEF TECHNICAL SUMMARY:
The goal of the Advanced Frequency Standard work unit is to develop reliable and economical ultra-stable frequency sources for the DSN with stability of parts in 10^{16} at averaging intervals $300 < \tau < 10{,}000$ seconds. The linear ion trapped frequency standard (LITS), developed at JPL, is presently being implemented for the DSN. Seven LITS units have been constructed to date including two research standards, four for the DSN and one for the US Naval Observatory (USNO). A compact research standard (LITE) is operational, with reduced size, increased operational flexibility, and further cost savings. An implementable version of the LITE has been designed and under construction. Recent tests for both the LITS and LITE show sharply improved S/N values which, when combined with an appropriate local oscillator (L.O.) such as the 10K CSO, will give improvement on hydrogen maser stability for all measuring times.

JUSTIFICATION AND BENEFITS:
The LITS standards, with their simplified physics package and inherently reduced environmental sensitivity, are substantially simpler to build and maintain compared to the hydrogen masers and will provide an estimated savings of $200K per unit installed and projected savings of $250K per year in maintenance costs starting in 1998. The implemented LITS units are now being installed in DSN stations, and further savings are anticipated in subsequent years with replacement of the remaining masers.

Continuing LITS research and development makes possible improved performance and reliability for the implemented units. The compact LITE research standard has now demonstrated performance and S/N to match that of the conventional LITS in a much smaller physical package, with a configuration that allows interrogation strategies that can reduce L.O. performance degradation. This is particularly of interest given the recent measurements of markedly improved S/N values that, when combined with improved L.O.'s, will allow substantial performance improvements.

APPROACH AND PLAN:
Development of the *Linear Ion Trap Standard* (LITS) at JPL has led to the design and fabrication of four operational laboratory standards, and a capability which is presently being implemented for the DSN. Performance of the linear design introduced by JPL is superior to previous trapped ion standards, so that by now other frequency standard development projects working with ions are primarily using this design. Even though these other projects involve research standards with enhancements such as laboratory lasers or individual ion interrogation, neither their demonstrated or even calculated (from measured S/N) stability matches that of the JPL standards. The measured stability the LITS is presently superior to any other frequency standards for time scales from several hours to several months.

Medium-term performance of the smaller LITE research trap now matches that of the standard LITS design, exceeding the goal for FY96 and establishing the validity of this approach. Longer term systematics are still being studied. Several design improvements and realizations have been incorporated in an implementable design which is now being built with completion expected by the end of FY97. The redesigned LITE physics package is also being installed in the USNO LITS unit under contract to them.

Recent improvements in LITS S/N through incremental improvements in optical signal size and background light reduction now rival present laser-interrogated Ytterbium research trap results. (It is worth mentioning that, as short-wavelength diode lasers become available, replacement of Ytterbium with Mercury will enable a quantum jump in laser-interrogated standard S/N performance.) While the stability inferred from the LITS S/N values is as low as $2\times10^{-14}/\sqrt{\tau}$, measured stabilities are limited to $5\text{-}10\times10^{-14}/\sqrt{\tau}$ by available hydrogen maser L.O.'s. However, when combined with an L.O. with sufficient short-term stability such as the cryogenic sapphire standards operating at 10K or below, the LITS performance should improve on that of hydrogen-maser standards for all time scales.

The improved LITS S/N places emphasis on L.O. performance but *also* on methodologies to reduce L.O. impact on LITS stability. Reduction of the L.O. degradation effects can be accomplished if the “dead time” during which the L.O. is uncorrected can be reduced.

In addition to the DSN LITS standards, an additional unit has been constructed for the US Naval Observatory (USNO). Interest in the LITS technology has been expressed by several industrial companies including Frequency and Time Systems in Beverly, Massachusetts. The primary candidate for commercialization is the new LITE compact trap design.

Long-term tests of the LITS will be conducted, with comparison both to frequency standards in the test facility, and (via GPS) to remote standards at NIST and USNO. One of the LITS units will be kept continuously operational for this purpose, and will also provide a frequency reference to allow the performance of developing standards to be better characterized at medium to long measuring times.

A primary task of this work unit is development of the compac*t Linear Ion Trap Extended* (LITE) standard. The first research unit has exceeded expectations, showing short-term performance of $8\times10^{-14}/\sqrt{\tau}$ and stability of 7 parts in 10^{16} for a measuring time of 10,000 seconds. Furthermore, S/N based short term performance is calculated to be $5.6\times10^{-14}/\sqrt{\tau}$, which would give $4.0\times10^{-14}/\sqrt{\tau}$ in an implementation-style unit with two collection systems.

Design has been completed and construction is underway for the implementable LITE standard, dubbed “super-shuttle”. Interrogation scenarios have already been investigated, giving rise to the advantage of a shorter dead time. A new magnetic shielding design is incorporated with improved performance, and a 12 rod trap design is being constructed to allow application of an ac magnetic field that can compensate the frequency shifts due to the changing number of ions in the trap. Further investigation is required to parameterize and optimize performance, in particular with regard to magnetic and rf fields in the “quiet” region.

A *Cryogenic L.O.* demonstration and test is planned for this FY to mate the developing sapphire oscillator capability to the LITS standard. With 3×10^{-15} L.O. this test will allow the first demonstration of the performance inherent in recent LITS S/N advances. This very high short term stability will require modification of the LITS multiplier chain to assure that the full L.O. stability is made available to the LITS atoms.

A *LASER-PUMPED Ytterbium* LITS standard in development shows even larger optical signals than the mercury LITS with negligible background. The development of the Ytterbium LITS standard has shifted toward a *laser-cooled* LITS capability that has now demonstrated cooling of atoms to sub-Kelvin temperatures in a linear (LITS) trap. A diode-laser optical pumping source is being developed toward converting this laboratory capability into a DSN standard. These observed signals theoretically enable a frequency stability of less than $1.6\times10^{-14}/\sqrt{\tau}$.

The recent laser-cooling demonstration for Ytterbium now points toward a first demonstration of a laser-cooled LITS frequency standard. Such a standard would show sharply reduced frequency offsets and greater accuracy compared to the present LITS units. Because cooling needs to be done more or less continuously, this will be demonstrated by sympathetically cooling a second Ytterbium isotope. This way, the laser cooling process will not unduly interfere with the frequency determination process. The cooling process of the clock ions is somewhat the same as the helium-cooling process presently used – however, the charged ions interact much more strongly than the neutral helium atoms, and so can cool more effectively. (A shift in emphasis from Laser Interrogation to Laser Cooling is partly due to the fact that the S/N for the LITS and LITE now outstrip the ability of available LO’s.)

DELIVERABLES:

- Continuing long-term Linear Ion Trap (LITS) Tests 10/98-9/99
- Implementable LITE Physics Package Demo 12/97
- Optimize Long-Term LITE Parameters 6/98
- Technology Transfer, LITE Standard to Commercial Manufacturer 6/99
- Demo $3\times10^{-14}/\tau$ performance for LITE and 10K CSO 6/98
- Demonstrate sympathetic laser cooling in Ytterbium trap 6/98

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)	320	350				670
Workforce (WY)		1.75				1.75
Co-funding ($K)						0
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Cryogenic Microwave Oscillator	
WORK UNIT IN WHICH FUNDED: Microwave Oscillator 412-41403	
WORK AREA: Frequency and Timing	

BRIEF TECHNICAL SUMMARY:
Develop cryogenic microwave oscillator capabilities with superior short-term stability and spectral purity to meet requirements of missions such as the Cassini Ka-band Experiment, and to meet L.O. requirements of the LITS standards. A sapphire oscillator operating at 10K with a closed-cycle cryocooler is being developed for stability of parts in 10^{16} at averaging intervals $1 < \tau < 1000$ seconds, and for the generation of spectrally pure signals at 8.1 and 32 GHz. This work is also being supported by the Cassini Ka-band Experiment.

JUSTIFICATION AND BENEFITS:
Requirements of the Cassini Ka-band Radio Science Experiment for short-term frequency stability and phase noise performance for occultation measurements in '03 can only be met with cryogenic microwave frequency standards such as the JPL-developed superconducting cavity maser oscillator (SCMO). Additionally, improvements in LITS stability to meet Cassini's medium-term goals for a gravitational wave search in '00 are possible only with such a cryogenic standard for an L.O. The 10K Compensated Sapphire Oscillator (CSO), operating with closed-cycle cooling, is being developed to meet these requirements at substantially less cost than the liquid helium cooled SCMO. This standard is designed for ease of implementation with a robust technology based on the 77K CSO development and on recent advances in available sapphire quality. In addition to improved operability without the periodic liquid helium transfers required by the SCMO, Initial cost savings over the SCMO design are estimated at $150K/unit, with maintenance costs reduced by $100K/year for three installed units. An implementation effort is planned starting in FY98, with continuing development required in support of this effort.

Advances in microwave technology now make possible the use of higher frequencies for spacecraft communication, which together with advances in tropospheric delay calibration and other TMO Technology, can now greatly reduce frequency degradation of spacecraft signals. New frequency standards such as the 10K CSO under development as part of a DSN upgrade for the Cassini Ka-Band Experiment are an integral part of the hardware capability required to match this increased stability.

The ultra-stable reference signals provided by the sources and distribution networks must be characterized with commensurate precision. Validation of the stability and spectral purity of references throughout the complex, and in deep space stations, is crucial to the success of science experiments. While not included as an explicit task in this or any other work unit, development of frequency characterization methodology is carried on in parallel with any clock technology that requires it. This capability allows experimenters measuring frequency and phase fluctuations to determine ultimate performance in their experiments.

APPROACH AND PLAN:
A 10K Compensated Sapphire Oscillator (CSO) with a closed-cycle cryocooler is being developed for stability of parts in 10^{16} at averaging intervals $1 < \tau < 1000$ seconds, and for the generation of spectrally pure signals at 8.1 and 32 GHz. Performance Requirements of the Cassini Ka-band Radio Science Experiment are a stability of 3-4. This project began with a study in FY95 and will begin an implementation phase by FY99. Continuing TMOD research support is projected through FY01 to enable continuing improvements in performance and reliability. This development supersedes the JPL-developed SCMO.

The *Superconducting Cavity Maser Oscillator* (SCMO), a cryogenic oscillator operating at liquid helium temperatures provides unsurpassed performance at short measuring times (1 second $< \tau <$ 100 seconds), with stability at τ = 1 second more than 10 times better than the hydrogen maser. SCMO #1 continues to be held operational, and available for use in the DSN for radio science requirements for ultra-high short-term stability.

The *77K CSO* development has been reevaluated, and may be superseded by a proposed effort towards a tiny *MM-wave Sapphire Oscillator* room-temperature unit with ultra-low close in noise. This unit could replace the USO in spacecraft for deep space missions, while still allowing the advantages of the USO for improved S/N at low bit rates.

The *10K Compensated Sapphire Oscillator* is being developed as a practical alternative to the SCMO, applying new whispering gallery sapphire resonator technology to a 10^{-15} short-term frequency standard. This standard incorporates an inexpensive commercial refrigerator for unattended long-term operation and low maintenance costs. Liquid-helium cooled sapphire resonators in the SCMO and in whispering gallery oscillators developed at the University of Western Australia are compensated at 1.5 - 6 kelvins by the presence of paramagnetic impurities which are incidental to preparation of the sapphire material. The gap-tuned 77K CSO design is inappropriate at this lower temperature where available sapphire Q's of $\approx 10^9$ are needed to achieve ultra-high stability. The new design adapts the CSO approach to the paramagnetic spin-compensation mechanism to achieve a turn-over temperature above liquid He temperatures. Thus, an elevated compensation temperature is achieved that can be reached with inexpensive and reliable 2-stage cryocoolers. Design of the 10K CSO was accomplished using the CYRES-2 finite-element program and the JPL Cray supercomputer.

This development is also being supported by the Cassini Radio Science Experiment. The first unit is now operational in a preliminary, uncompensated, configuration. Stability is presently 3×10^{-14} between 10 and 100 seconds, with shorter time data obscured by the hydrogen maser fluctuations. Without compensation, the temperature sensitivity is approximately 300 times larger than we expect for our final configuration where resonator temperature will be held within 10mK of the compensation point. With the random walk of frequency character shown by the data, this thermally-limited stability extrapolates to 1×10^{-15} for all times less than about 1000 seconds. A cryocooler has been ordered for the second unit to be completed in FY98, and the cryostat and nearly all other components for the second unit will be ordered in FY97. In particular, sapphire resonator elements for 6 CSO units have been ordered. Microwave electronics for the present demonstrations are based on those for the 77K CSO, and the short-term limitations of that configuration are presently masked by H-maser noise. A full demonstration of 10K CSO performance will only be possible when the second CSO unit is completed later in FY98.

DELIVERABLES:

- Compensated Sapphire Resonator Optimization 12/97
- Second 10K CSO Operational 6/98
- Demo 3-4x10^{-15} stability 8/98
- Technology Transfer 10K CSO 9/98
- TDA Progress Report on 10K CSO Oscillator 2/98

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)	160	100				260
Workforce (WY)		0.5				0.5
Co-funding ($K)		450				450
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Photonics for Frequency Standards	
WORK UNIT IN WHICH FUNDED: Photonics 412-41404	
WORK AREA: Frequency and Timing	

BRIEF TECHNICAL SUMMARY:
Develop fiber-optic systems for the distribution and conversion of frequencies and wide-band signals at X- and Ka-band with stability of parts in 10^{17}, and for generation of ultra-stable signals in a compact, flyable package. Photonic transmission systems are being developed and demonstrated for wide-band signals to allow practical antenna remoting for the DSN. A photonic oscillator is being developed that offers stabilities in the 10^{-14} range with X- and Ka-band operation at room temperature with size and weight well matched to flight oscillator requirements.

JUSTIFICATION AND BENEFITS:
The development of ultra-stable frequency standards with performance exceeding the current state-of-the-art must be augmented with distribution systems capable of sustaining the stability of the source. A network capable of distributing stable references from a centralized location within a complex to multiple deep space stations provides operational advantages and economy. Such a network enables advanced navigational concepts such as connected element interferometry and carrier arraying, which require coherence between two or more stations.

Fiber-optic signal transmission provides unmatched stability, frequency response, and immunity to interference, crosstalk, and ground-loops. This capability has proliferated throughout the DSN to distribute hydrogen maser quality references from centralized locations throughout DSN complexes. As the state of this art advances, new capabilities are becoming available that tend to require less and less equipment at the antenna site (antenna remoting) with associated greater flexibility of operation and lower operations costs. These new capabilities are X- and Ka-band reference transmission, X- and Ka-band wide-band signal transmission with high dynamic range, and photonic signal transformation capabilities.

Recently demonstrated broad-band microwave distribution capability, also with ultra-high stability, makes possible a simplified structure for the station, with microwave signals transmitted directly from the antenna to the control room without downconversion. All-photonic and mixed photonic/rf systems are under evaluation that allow a substantial reduction in the amount of equipment at the antenna itself, and would replace the reference frequency and IF links between the station and the antenna. They also enable the transmission of wideband signals between multiple antennas for improved signal-to-noise and novel experimental needs.

A photonic oscillator, the opto-electronic oscillator, or OEO, is under development that promises ultra-high stability in a small and inexpensive package. The is a new class high performance microwave/millimeter wave oscillator invented and developed here at JPL. It is based on converting continuous optical energy into high spectral purity microwave oscillation. This technology is extremely attractive as a flight capability, offering 10^{-14} stability with a new and rapidly advancing technology. It is much more attractive than the cryogenic oscillators for space applications, either as a high-performance L.O. for a LITS-type standard, or for its own excellent stability. In addition to its attraction as a possible flight oscillator, this technology offers a room-temperature alternative to the cryogenic oscillators as an improvement over available crystal oscillator L.O.'s for the trapped ion standards.

Substantial cost savings are possible with an advanced photonic-based architecture, especially if designed into new installations. An evaluation of these savings is presently in process. The scale (and expected performance) of the developing photonic oscillator technology lies between that of present quartz oscillators and the much larger 10K CSO, offering a cost-effective alternative as LITS L.O. that would exhibit improved operability associated with room temperature operation. It could function in a stand-alone capacity, or as a backup to the CSO, with cost savings of at least $200K per installation.

APPROACH AND PLAN:

JPL photonic research enables the use of new capabilities by testing and demonstrating high-frequency and broad-band capabilities as they are developed by industry, and by feeding back results of our evaluations to the manufacturers. A more traditional research approach is necessary for photonic needs that are unique to the DSN and for new and useful technologies that are developed at JPL. Photonic and photonic/rf signal transformation techniques under development for antenna remoting are presently being evaluated, and a demonstration system will be installed for testing by the JPL radio science community in FY98. Work to date shows that lasers and detectors have the required performance for implementation of a combined photonic frequency distribution, signal distribution, and down-conversion in the DSN at frequencies up to Ku band, and should reach Ka band within several years. A photonic oscillator is being developed that offers parts in 10^{14} stability in a very small room-temperature package and which can be used both for DSN L.O. and for spacecraft applications.

Photonic signal transmission and conversion methodologies are being developed and evaluated for transmission and frequency conversion of wide-band microwave signals up to Ka band with dynamic range greater than 150 dB. The impact of these capabilities on DSN architecture is also being analyzed. An installation at DSS-13 is being prepared to demonstrate in an operational context the antenna-remoting capabilities. One of the problems of the Goldstone complex, as opposed to the other DSN sites, is a large distance scale of up to 30km. An Erbium-doped fiber-amplifier, powered by a 980nm laser source, has been purchased to boost the optical signal levels and so allow operation over this larger distance. An IF converter is being obtained to allow this test.

A photonic down-conversion configuration for the DSS-13 demo is also enabled by the Er fiber amplifier, by overcoming additional losses due to multiple optical modulators in the same optical path. A polarization-insensitive configuration will be studied that allows this all-photonic configuration without transmitting reference signals to the antenna site.

An *Optoelectronic Oscillator* is being developed that offers ultra-high stability in a small, room-temperature package that is suitable for either flight or ground-based applications. This OEO operates at an rf frequency which is determined by a length of optical fiber, and combines optical components with ultra-low noise electronic components for modulation and detection. Its operating power derives from the laser light source, and frequency-stable operation is enabled by a fiber with nominally zero sensitivity of group delay to temperature. .

Several new developments in ultra-low noise technology now show great promise for application to the OEO. The first application of the Brillouin amplification process to the OEO technology this past year promises to eliminate the need for any other amplifying element in the oscillator. The Brillouin fiber-optic amplification process developed at JPL uses a counter-propagating optical signal from the laser to directly amplify the rf sidebands on the optical signal in an ordinary fiber. The amplification process is optimized at one particular frequency for any given laser wavelength and fiber, and for the 1320 NM laser and low thermal fiber currently used, this frequency is conveniently 12.8 GHz. “Amplifierless” oscillation has now been demonstrated at 12.8 GHz using a long (10km) fiber as required for ultra-stable operation – this had been previously possibly only at VHF frequencies. A dual-loop configuration is now being designed to eliminate the mode-hopping that the signal presently shows. With this, the flicker characteristics of this amplification process can be measured for the first time. The only remaining semiconducting device in the circuit is the detector which is a Shottky device and so is expected to show very low flicker noise. We have not been able to verify this because of masking amplifier noise (see next paragraph).

A second development is the application of carrier suppression techniques to the optical realm for the reduction of multiplicative noise. This technique, developed and analyzed at JPL to enable ultra-low noise operation in cryogenic oscillators, is now widely used in microwave applications by frequency and timing community, but has not been previously applied to the optical realm. The technique has application both to frequency sources themselves, but also to the characterization of noise in components that have very low noise, a task which is crucial to the development of this new technology.

The results to date are very promising, and in particular, a predicted independence of phase noise performance to rf frequency was confirmed. Recent measurements of close-in phase noise are in excellent agreement with results of component flicker noise sources. A thermally isolated fiber delay has been constructed and is currently under test. Integration of stable fiber into remaining components (e.g. fiber component pigtails) will enable high stability operation (10^{-12} or better) in FY99.

DELIVERABLES:

- Field installation, X-band link with 30km capability 12/97
- Demo all- photonic link including down-conversion 3/98
- Demo all-photonic polarization-insensitive link 7/98
- Demo Opto-Electronic Oscillator with thermally stabilized delay 3/98
- Construct dual-loop Brillouin OEO 2/98
- Demo OEO at 10^{-12} stability 6/99
- Transfer Technology OEO 6/00

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)	200	170				370
Workforce (WY)		0.8				0.8
Co-funding ($K)		400				400
Projected Savings ($K)						0

TMO TECHNOLOGY TASK DESCRIPTION

TITLE: Optical Frequency Standard	
WORK UNIT IN WHICH FUNDED: Optical Frequency Standard	
WORK AREA: Frequency and Timing	

BRIEF TECHNICAL SUMMARY:
TBD

JUSTIFICATION AND BENEFITS:
TBD

APPROACH AND PLAN:
TBD

DELIVERABLES:
TBD

RESOURCE REQUIREMENTS:

	Prior Year	FY98	FY99	FY00	FY01	Total at Completion
Funding ($K)	0	75				75
Workforce (WY)		0.4				0.4
Co-funding ($K)						0
Projected Savings ($K)						0